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A top-down analysis of the cost structure of a US air war was performed with the aim of elucidating the importance of aircraft range to campaign cost. The principal conclusion of this study is that, historically, operations and support (O&S) cost dominated the cost of an air war due to the large number of sorties required to deliver the large volume of relatively inexpensive, low-precision munitions needed to destroy a specific target. The advent of precision munitions has dramatically reduced the number of sorties needed to such a degree that now basing costs dominate the current force's cost structure. These findings imply that long aircraft range is currently more valuable than it has been historically, and deserves more emphasis in the technical community than it has enjoyed in the past. Therefore, a reassessment of S&T investment may be warranted. A range of 12,000-13,000 nmi is required for world-wide coverage from domestic bases; it appears several approaches are feasible for realizing such a capability. One technical approach of particular interest is a supersonic, oblique flying wing aircraft.

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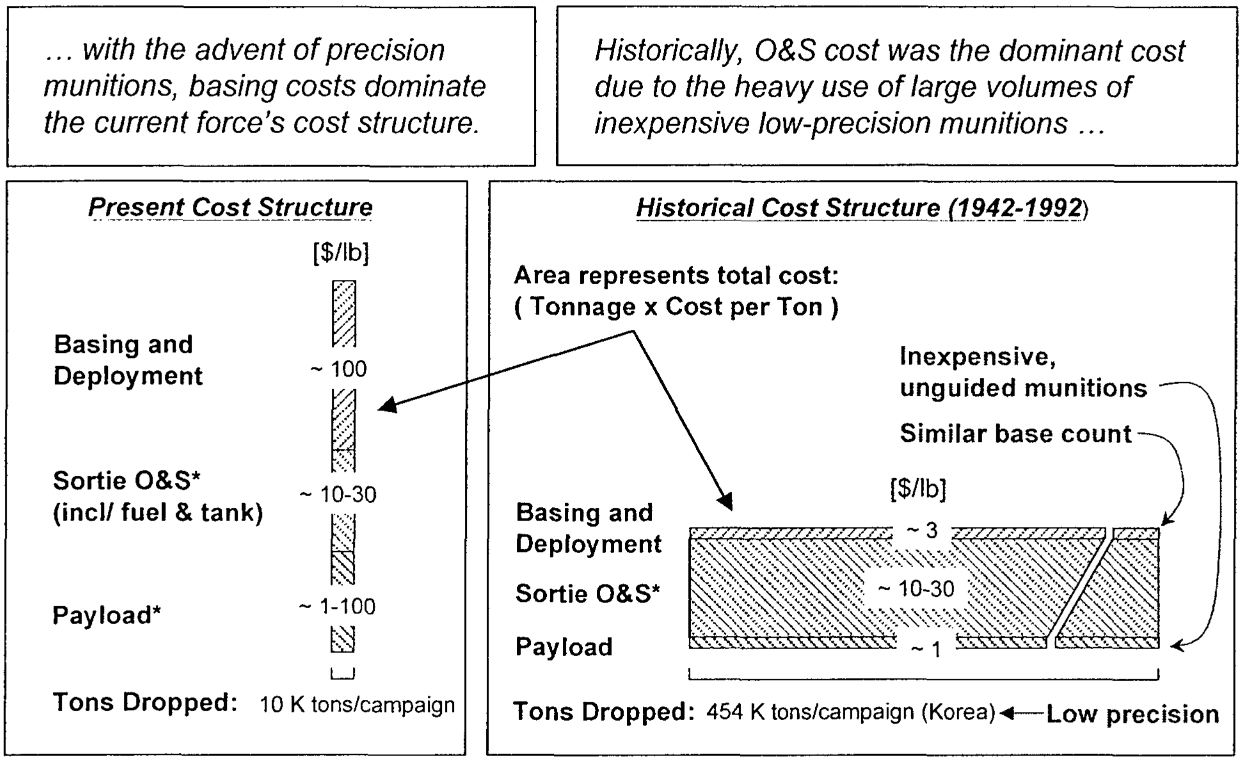
SUMMARY

A top-down analysis of the cost structure of a US air war was performed with the aim of elucidating the importance of aircraft range to campaign cost. The principal conclusion of this study is that, historically, operations and support (O&S) cost dominated the cost of an air war due to the large number of sorties required to deliver the large volume of relatively inexpensive, low-precision munitions needed to destroy a specific target. The advent of precision munitions has dramatically reduced the number of sorties needed to such a degree that now basing costs dominate the current force's cost structure, Figure 1.



•Note: Calculation adjusts only basing costs. Calculation excludes differences in payload costs and sortie costs.

Fig. 1: Historical evolution of cost structure.

The implication of these findings is that long aircraft range is currently more valuable than it has been historically. It is clear that the value of range is now such that it deserves more emphasis in the technical community than it has enjoyed in the past. This therefore suggests that a reassessment of S&T investment may be warranted. A range of 12,000-13,000 nmi is required for world-wide coverage from domestic bases and it would appear that there are several feasible approaches to realizing such a capability. One technical approach of particular interest is a supersonic, oblique flying wing aircraft. Full assessment of the relative value of various basing approaches must consider many technical, political, and diplomatic issues, and so is beyond the scope of this study but could fruitfully be pursued in a follow-on effort.

INTRODUCTION

"The problem of Afghanistan is the tyranny of distance," said the then-Commander of the US Eighth Air Force early in 2002. This stands in contrast to the challenges of the cold war. Then, the US Air Force was designed to protect Europe and Japan from the Soviet Union. As such, it was then and is today mainly equipped with short-range aircraft which depend upon aerial refueling to extend mission durations as needed. This strategy is based on having well-defined threats and allies with geographically appropriate bases ringing these threats. The world is now a much different place. Modern threats can be ill-defined, diffuse, and remote. The concept of allies has also taken on a different connotation, given a lack of consensus on the nature and seriousness of international threats. In this context, one can ask if the US has the appropriate Air Force in place and in plan.

The optimum range and speed of air vehicles has been examined numerous times in systems studies and aircraft conceptual design exercises. Major concerns for such studies include such factors as total cost to prosecute a campaign, responsiveness to time-critical threats, and target mix. What's changed? Why do yet another study? The answer lies in the realization that past studies have been based upon assumptions that are not now true. The first assumption was that the cost of fuel at the nozzle of a tanker was the same as the Air Force paid to the Defense Logistics Agency. A 2001 DSB study has pointed out that this is a significant understatement. (The report quotes $17/gal as the true cost in 1998, not including the cost of the tanker aircraft, verses the $0.90 the Air Force charged users.) This implies that aerial refueling is a much more expensive proposition than was apparent under traditional accounting practice. The second assumption concerns the availability of bases. While bases were widely available during the Cold War, they are not necessarily as readily available today. In war, negotiations for basing rights can be lengthy and the resultant rights expensive (in many senses). The costs of such bases have not typically been included in analysis of the cost of fighting a war or in assessments of the relative merits of various approaches and systems.

The Air Force operates with the organizational concept of an Air Expeditionary Force which can deploy to austere bases (perhaps only runways exist) in a few days. In such a deployment, the third C-17 carries the first fire truck. Then the foam, the firemen, their tents, messes, etc. must all be airlifted in. This is a very expensive process. It also ties up airlift assets which the ground forces depend on for their rapid deployment forces. In recognition of the heavy logistical burden intrinsic to the Air Expeditionary Force concept, the Air Force leadership challenged its technical community to reduce the mass of the expeditionary force by an order of magnitude. To date, little progress has been made toward reaching this goal.

Under current operational scenarios, in the early days of a conflict ordinance may be delivered to a newly established airbase by airlift. For example, a C-17 operating at a 4500 nmi radius and delivering a payload of 165,000 lbs to a remote base requires three aerial refuelings. Together, the cargo plane and the tankers burn 730,000 lbs of fuel. Once the ordinance arrives on base it is then loaded onto a short-range tactical aircraft such as an F-15E which is in turn refueled once or twice to release the (these days) guided ordinance and return to base.

Given the above costs (both direct and indirect) of having a short-range Air Force, it is logical to ask why not develop aircraft of sufficient unrefueled range that they can be based in the US? Many benefits are obvious as are costs. In the first days of a war, this holds the possibility of immediate response, and combat need not wait on base procurement and deployment. For longer conflicts and peace-keeping missions (which in recent years represent a hitherto unprecedented deployment and operations tempo), it removes the need for overseas air

bases. This collapses the military logistics trail since domestically FedEx can move material, civilian police and contractors provide security, etc. It also improves personnel retention, since military personnel are no longer separated from their families for many months. Eliminating the need for tankers reduces the number of aircraft (and supporting personnel and logistics) needed to prosecute a campaign. It also frees up tankers for servicing shorter-range assets. Indeed, prolonging the life of the current tanker fleet may free up the funds needed to procure very long-range aircraft.

Many costs are also obvious. At a constant level of technology, the longer-range aircraft will carry less payload for the same takeoff weight. Long-range aircraft are less efficient than other options for shorter-range operation, so some degree of flexibility is lost. With current technology, a vehicle optimized for maximum range may sacrifice other needed attributes such as survivability. If subsonic, mission duration is very long, taxing crew endurance (assuming these are crewed vehicles). Finally, current technology can deliver only so much range-payload at reasonable aircraft size and required survivability, which may not be sufficient to fulfill all mission requirements.

Global range is not a new concept but rather a subset of "Global Reach", a goal discussed in previous studies such as those by the Air Force Scientific Advisory Board. What is new is the realization that the cost accounting basis of previous studies was flawed from the perspective of the early 21st century – tanker fuel and air bases are not cheap, and base availability must not be assumed. The study will explore the influence of these factors on optimal (in a systems sense) aircraft design and delineate the technology investment areas needed to realize them.

Rather than perform detailed scenario analyses, the paper examines the force structure of the USAF from a "top level" perspective, using top-down modeling and estimation techniques.

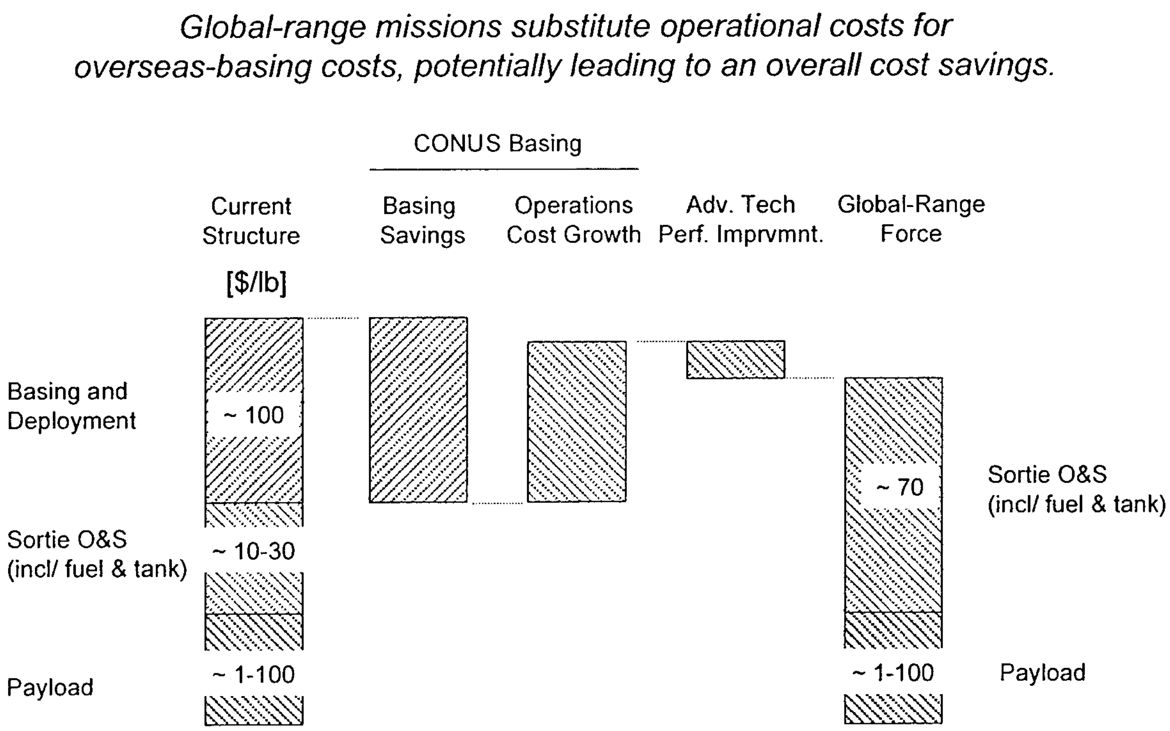


Fig. 2: Cost of the USAF infrastructure.

Analysis starts by building a parametric model of the existing Air force cost structure such as illustrated in figure 2. Consistent with sound financial analysis principles, this model is built with the greatest possible level of cost granularity, and then "rolled up" to produce top-level cost estimates. The granular cost model accurately captures the fundamental causal financial and physical relationships that determine force cost. Cost accrual is "fully-loaded" and activity based. The activities used for cost accrual are modeled using physics-based models. Specifically, the cost model accounts for allocated base costs and "at-the nozzle" fuel costs that include tanker ownership and operating costs. The activity-based cost-model also uses the Breuget range equation to calculate aircraft fuel consumption. The following sections describe the cost model in further detail.

COST MODEL OVERVIEW

The costs are divided into three broad categories: Payload Costs, Platform Operating and Support Costs, and Basing and Deployment Costs (Figure 3) which are described in the following subsections.

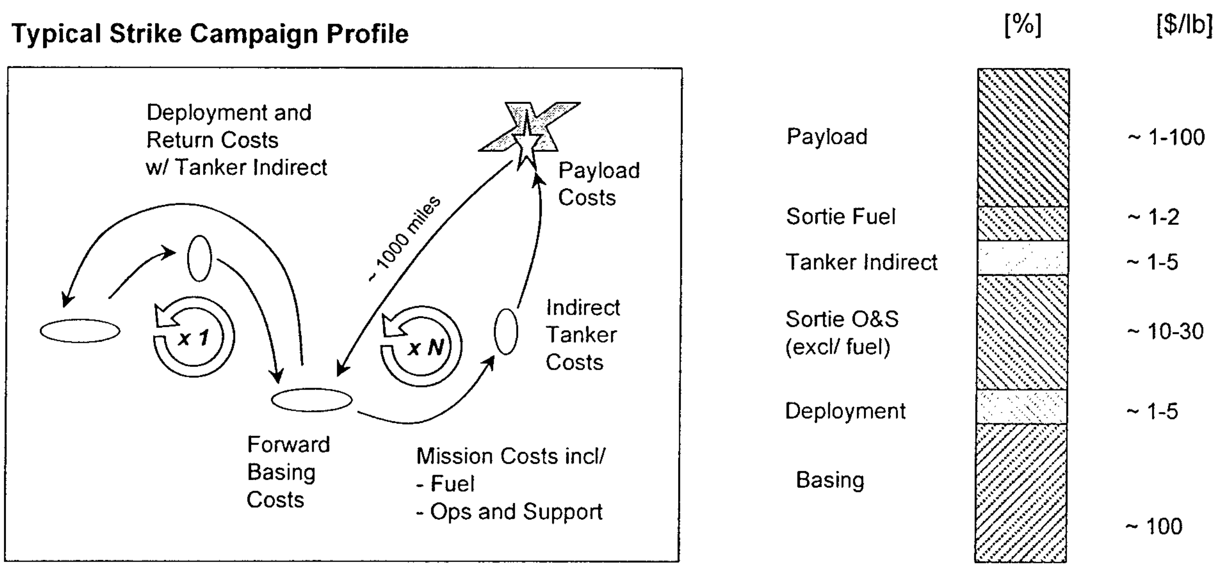


Fig. 3: Cost of USAF infrastructure. The costs associated with the current USAF infrastructure were divided into six major categories.

Payload Costs

Payload costs, Figure 4, are the most direct, and most easily modeled, of the force structure costs. Per-unit purchase costs for existing payloads use replacement cost or fly-away cost. Per-unit costs for hypothetical payloads, or payloads that are currently in development, use fly-away cost plus allocated development cost. For strike missions, the principal payload cost is the replacement cost of expended munitions.

Depending on the sophistication of the payload, payload costs can be the smallest or largest cost category for a strike mission, with a cost range of 1-100 $/lb. Standard JDAM guided bombs cost approximately $10/lb.

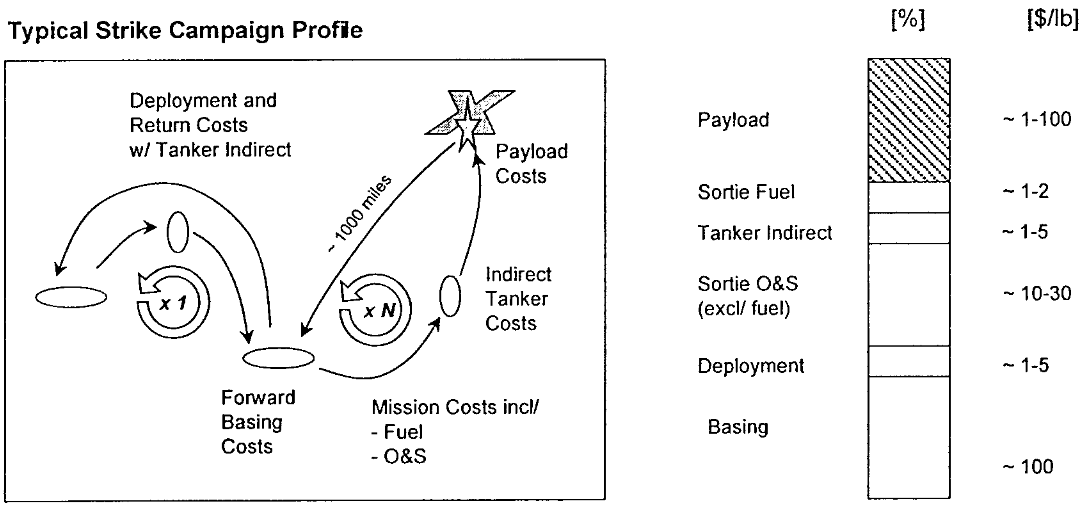


Fig. 4: Payload costs.

Figure 5 plots the replacement cost for current US bombs and missiles as a function of stand-off range. Munitions costs can range from $1/lb for an unguided, zero-stand-off, "dumb" bomb to $300/lb for SLAM, a guided air-to-ground missile with a stand-off range of 60 miles. Depending on mission profile and munitions type, payload costs can represent from as little as 1% to as much as 75% of the total average campaign cost.

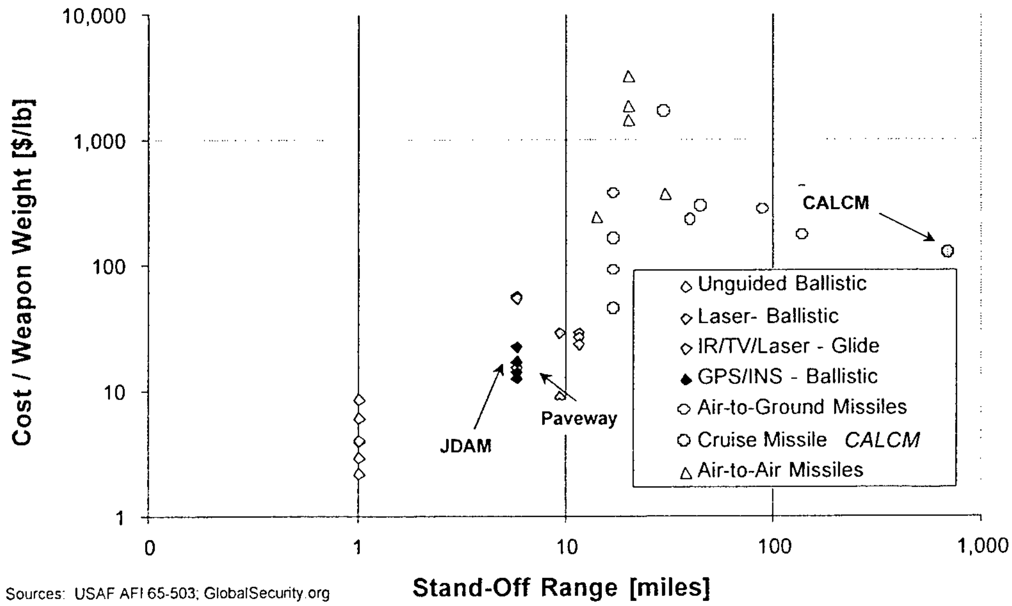


Fig. 5: Weapon (payload) costs vs. weapon stand-off range.

Recent Air Force operations in Kosovo, Afghanistan, and Iraq made extensive use of the GPS-guided, 1000-lb, GBU-31 JDAM bomb. This bomb, which has a stand-off range of up to 3 miles and a replacement cost of $20/lb, was used as the baseline payload for financial modeling purposes. Assuming a JDAM payload and a typical campaign and deployment profile, payload costs represent approximately 10% of the total average campaign cost.

Platform Operating and Support Costs

After payload costs, platform operating and support (O&S) costs are the most direct costs for a campaign (Figure 6). O&S expenses include fuel, platform depreciation, platform attrition, air crew labor costs, maintenance labor costs, maintenance materials costs, etc. They also include all overhead labor costs that can be directly associated with a squadron (squadron military and civilian support staff).

This study estimates that non-fuel O&S costs for the current force structure are on the order of $10/lb/1000-miles for most USAF aircraft, representing approximately 10-30% of the total typical campaign cost. Fuel-related O&S costs are estimated at $10/lb/1000-miles, or 10% of the total typical campaign cost. A more detailed explanation of the O&S cost model is presented below.

Operations and support costs account represent the second largest non-payload cost category, with a typical cost on the order of 10-30 $/lb for a 1000 mile mission.

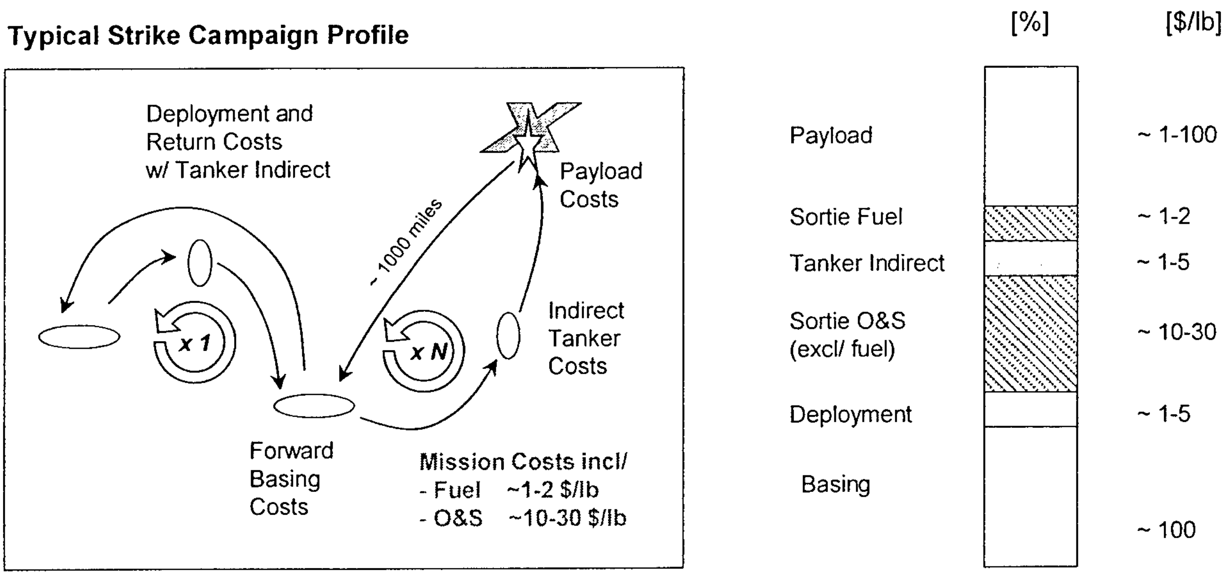


Fig. 6: Operating and support(O&S) costs.

Non-Fuel Operations and Support Costs

The cost model treats fuel and non-fuel O&S costs separately (Figure 7). The O&S cost model starts with publicly-available Air Force non-fuel O&S cost factors for each platform type. Non-fuel O&S expenses were grouped into four major categories: (1) crew, operations, and staff personnel, (2) maintenance and maintenance personnel, (3) depreciation, and (4) attrition.

Expenses in each category were estimated for each USAF platform type using publicly-available Air Force cost factors. Expenses were allocated on either a per-flight-hour (FH) basis or a per-platform-per-year (PAA) basis according to the instructions of the data source. Figure 7 lists the complete set of Air Force cost factors considered, together with the categorization, allocation method, and data source used for each expense.

Operating costs for each platform are built up from publicly available USAF budget data and are allocated per aircraft or per flying hour.

Cost	Input Data	Allocation	Data Source*^
Crew/Ops	Crew Levels Other Ops Personnel Pay Rates	Aircraft	AFI 65-503
Fuel	Range Payload Fuel Spot Price	Flying Hour*	Performance. Model AFI 65-503
Maintenance	Maintenance Crew Levels Pay Rates	Aircraft	AFI 65-503
	Organic Maint by A/C Contract Maint by A/C	Aircraft	AFI 65-503
	Organic Maint by FH Contract Maint by FH	Flying Hour	AFI 65-503
Depreciation	Fly-Away Cost Service Life	Flying Hour	AFI 65-503 GlobalSecurity.Org
Attrition	Fly-Away Cost Attrition Rates	Flying Hour**	AFI 65-503

Notes:
* Fuel Cost is allocated nonlinearly to flying hours as a function of range using the Performance Model.
** AFI 665-503 Attrition rate model is linearized around FY 03.
*^ AFI 65-503 data can be found at ____________ GlobalSecurity.Org data can be found at www.globalsecurity.org

Fig. 7: Modeling platform operating costs.

The cost model next adjusted the Air Force cost factors to more accurately capture the causal relationship between platform usage rate and O&S expenses. The Air Force non-fuel O&S cost factors divide broadly into per-flight-hour cost factors and per-platform-per-year cost factors. Equipment-related expenses are reasonably allocated on a flight hour basis because these expenses are strictly usage-driven, and because flight hours represent a reasonable measure of usage[1]. However, care must be taken with the per-platform-per-year cost factors.

Figure 8 shows that nearly all of the per-platform-per-year cost-factors are labor-related. Labor-related per-platform-per-year costs will be proportional to platform usage rate, platform labor intensity, and labor annual salary, and inversely proportional to labor productivity. The

[1] Per-flight-hour allocation of expenses such as platform depreciation or maintenance part expense is reasonable, but not perfect. Such expenses are usage-driven, but may not be strictly proportional to flight time. For example, wear-and-tear on an aircraft engine, and the consequent parts expense, are dependent on mission profile. Because much of the wear occurs at take-off or at other times when the engine is operated at high power levels, a single long mission should incur less maintenance expense than several shorter missions.

annual salary for labor is typically fixed by contract, and the labor intensity of a platform is typically fixed by engineering. To maintain a fixed per-platform-per-year cost factor, labor productivity must change in proportion to changes in platform usage. Such a relationship can hold in the short term when there is a temporary period of increased platform usage. Fixed per-platform-per-year cost factors are therefore appropriate for modeling occasional deployments, temporary changes to planned platform utilization, and other short-term changes in force structure. However the relationship will not hold for large, long-term shifts in platform usage.

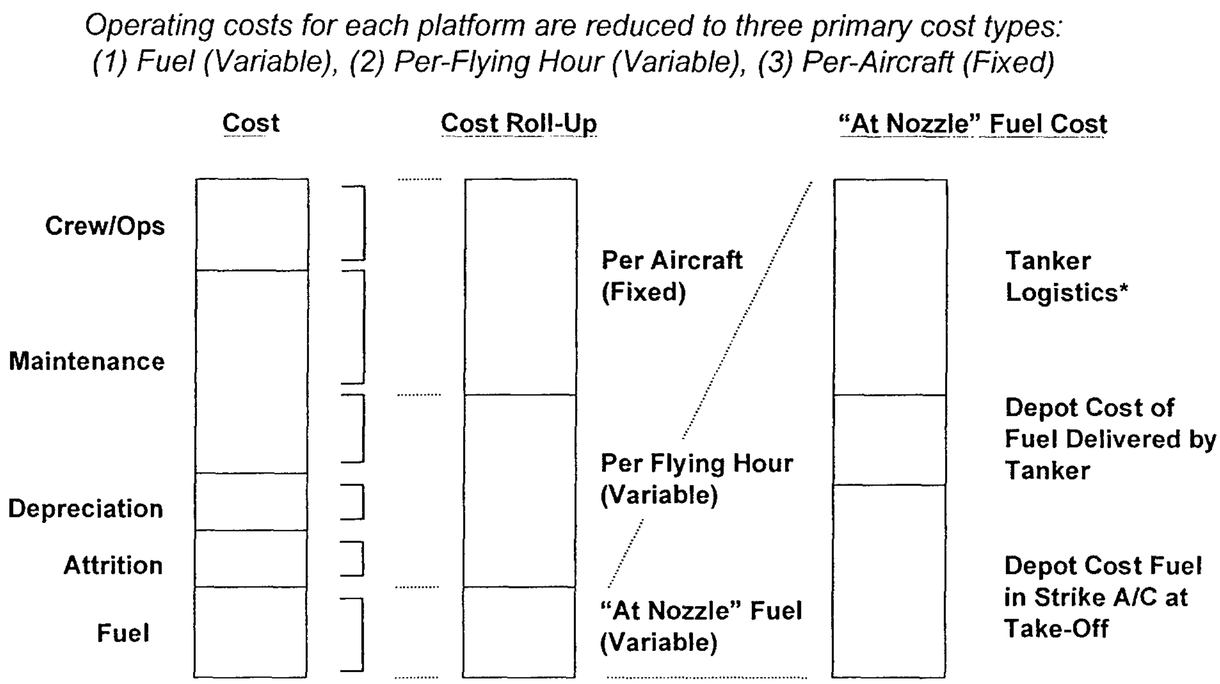


Fig. 8: Simplifying operating costs.

When large increases in platform usage occur, productivity levels cannot be expected to grow in proportion because there is an upper limit for labor productivity set by the available time in a work day. Beyond this limit, productivity must be assumed fixed and labor-related expenses must grow as the labor force itself grows.

For the purposes of this force structure study, then, it is more appropriate to assume that labor productivity is fixed and that labor-related expenses vary with platform usage according to an effective per-flight-hour cost factor. Per-platform-per-year cost factors for each platform type were allocated evenly across all flight hours by dividing these cost factors by the average annual usage rate for that platform type. This allocated cost factor was then summed with the equipment-related per-flight-hour cost factors to yield a total per-flight-hour O&S cost factor for each platform type.

The cost model next adjusted for the fact that not all platform usage is combat-related. The bulk of the annual flight hours for most current aircraft types are not combat mission hours, but hours flown to maintain air crew and ground crew proficiency. As a result, fully-loaded per-combat-flight-hour O&S cost estimates must include the costs of the associated training and proficiency flight hours.

The cost model allocated peacetime flight hours to combat flight hours through a utilization factor that scaled combat flight hours, or utilization, to total flight hours, or usage. Finally, the O&S expense per combat flight hour was converted to O&S expense per weight delivered using a platform performance model.

For each platform type and mission radius, the performance model calculated the allowable platform payload using the Breuget range equation and five platform performance parameters: (1) lift-to-drag ratio, (2) thrust specific fuel consumption, (3) cruise speed, (4) maximum gross take-off weight, and (5) and maximum payload weight. Mission duration, in flying-hours, was calculated from cruise speed, mission radius, and, for loiter missions, loiter time. Mission duration in flying hours was combined with the O&S expense per combat flight hour to yield fully-loaded O&S expense. This was combined with the payload calculation to yield fully-loaded O&S expense in dollars per weight delivered as a function of mission radius.

For short-range strike missions[2], the Breuget range equation can be linearized, and O&S costs will scale in proportion to mission radius (Figure 9).

For short-range missions, both O&S and fuel costs are proportional to mission radius. O&S costs (fully loaded) are the dominant contributor for current platforms.

Short Range

$$\frac{R}{V} << \frac{L/D}{TSFC}$$

$$\frac{COST_{FUEL}}{PAY} \approx P_{FUEL}\cdot\left(1+\frac{EMPTY}{PAY_{MAX}}\right)\cdot\frac{TSFC}{L/D}\left(\frac{R}{V}\right)\left(1+\frac{FH_{PEACE}}{FH_{COMBAT}}\right)$$

$$\frac{COST_{O\&S}}{PAY} \approx \left[\frac{O\&S_{PAA}}{FH_{PAA}}+O\&S_{FH}\right]\cdot\frac{1}{PAY_{MAX}}\left(\frac{R}{V}\right)\left(1+\frac{FH_{PEACE}}{FH_{COMBAT}}\right)$$

Unrefueled w/ O&S costs assumed by flight hour or yearly

$$\frac{COST}{PAY} \approx \frac{1/V}{PAY_{MAX}}\cdot\left[\frac{O\&S_{PAA}}{FH_{PAA}}+O\&S_{FH}\right]\cdot R + P_{FUEL}\cdot\left[1+\frac{EMPTY}{PAY_{MAX}}\right]\cdot\frac{TSFC}{L/D}\cdot\frac{1}{V}\cdot R \quad \mathbf{x} \quad \left(1+\frac{FH_{PEACE}}{FH_{COMBAT}}\right)$$

Platforms	O&S Costs [$/lb/1000 miles]	Fuel Costs [$/lb/1000 miles]	x	Utilization Factor
OA/A-10A	2.5	0.3		10
F-117A	-	-		-
F-15E	2.2	0.3		10
F-16C/D	3.3	0.2		10
B-1B	1.1	0.1		10
B-2A	-	-		-
B-52H	1.0	0.1		10
Hypothetical UCAV/URAV	1.1	0.05		1

Fig. 9: O&S costs dominate at short range.

Several caveats should be noted. Because the current Air Force cost structure is primarily built around a fleet of short-range aircraft, and the operating and support cost model

[2] Roughly, short-range missions are those less than 1000 miles in mission radius. Specifically, for this study, a mission is considered short-range for a platform if the linearized Breuget range equation for that platform approximates the corresponding full Breuget range equation to within 10%.

described above is based on cost factors that are meant to model that fleet, the operating and support costs of a primarily long-range fleet may be impacted in ways not currently modeled. For example, the deployment of a fleet of long-range strike platforms may necessitate upgrades to existing domestic bases. As another example, the maintenance costs of a long-range strike aircraft will almost certainly be lower than those of a short-range strike aircraft on a per-flying-hour basis due to the reduction in the number of take-off and landing "cycles" that would be associated with each flying hour. If the asset base must grow for long-range strike, there may be affiliated costs; long-range strike uses asset base differently, for example, may require larger asset base.

Compare, for example, a fleet of long-range platforms, each with a 20,000 lb payload, to a fleet of short-range platforms, each with a 20,000 lb payload (Figure 10). In order for the long-range fleet to achieve the same sortie rate, and thus the same level of campaign intensity, as the short-range fleet, it would have to involve significantly more platforms in a single campaign. This is because each platform would spend more of its time en route to and from the target area. On the other hand, the long-range fleet could strike any location of the globe on short notice while the fleet of short-range strike platforms would have to be redistributed to various theaters around the globe. Thus, while almost the entire long-range fleet could be engaged in any given campaign at any given time, only a small fraction of the short-range fleet would be engaged at any given time. This tradeoff may mean only a small net increase in asset base for long-range strike.

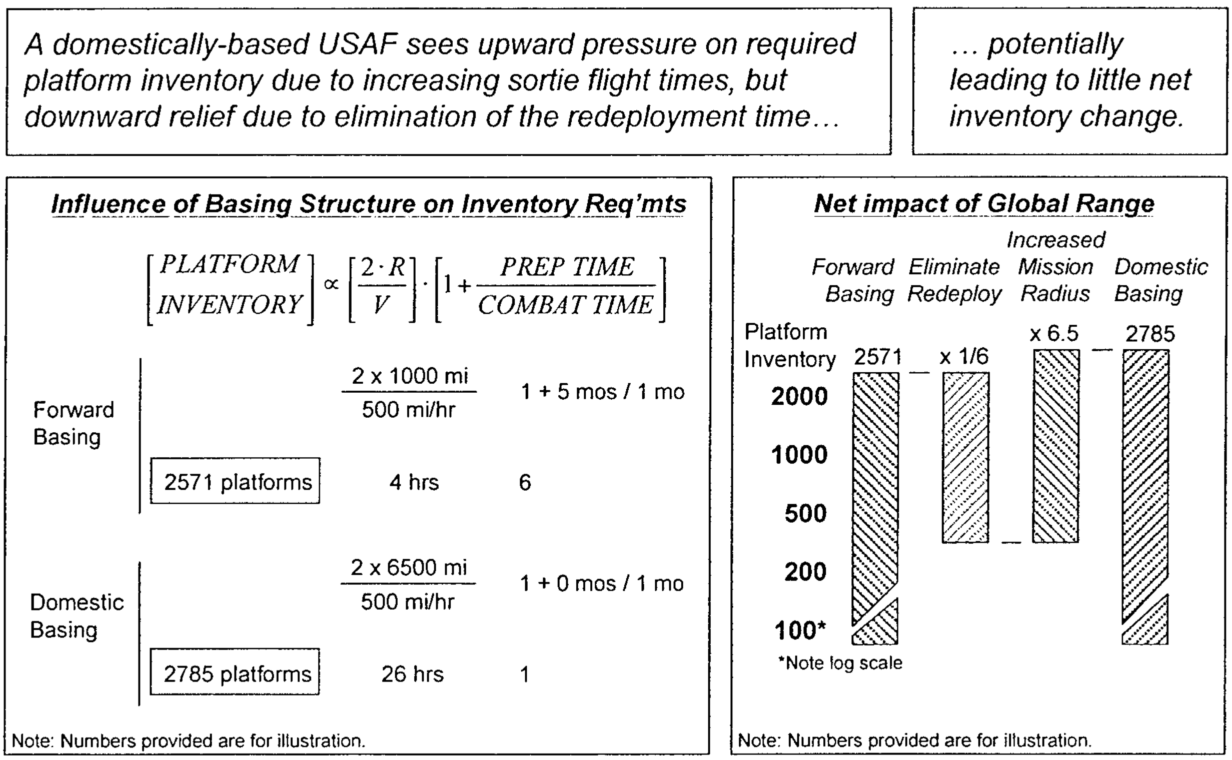


Fig. 10: Inventory requirements for global range USAF.

Fuel Costs

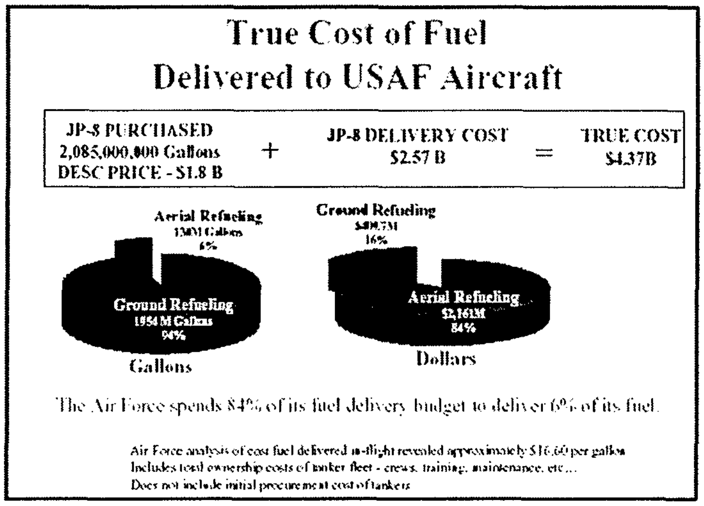
Estimation of fuel costs is one of the two primary differences between this study and other similar studies of USAF cost structure. Motivated by the results of a Defense Science Board, DSB, study (Figure 11), this study includes a "fully-loaded," physics-based model of refueling costs.

Fuel delivered via aerial refueling is considerably more expensive than fuel carried at takeoff due to the underlying operations and support (O&S) of the tanker fleet.

Depot cost of USAF JP-8: $0.99 / gal

Average cost of USAF JP-8: $2.1 / gal

USAF/DSB estimated cost of tanker JP-8 at the nozzle: $16.60 / gal



"The DoD currently prices fuel based on the wholesale refinery price and does not include the cost of delivery to its customers. This prevents an end-to-end view of fuel utilization in decision making, does not reflect the DoD's true fuel costs, masks energy efficiency benefits, and distorts platform design choices."

– Defense Science Board, January 2001

Fig. 11: The DSB found aerial refueling is expensive.

A January 2001 study by the Defense Science Board noted that "the DoD currently prices fuel based on the wholesale refinery price and does not include the cost of delivery to its customers." Specifically, the standard USAF method of allocating fuel costs accounted for the purchase cost of fuel, but did not account for the cost of owning and operating the tanker fleet. Using data for the total operating cost of the USAF tanker fleet and data for the total volume of fuel delivered by USAF tanker, the DSB estimated the average cost of tanker-delivered fuel to be $16.60/gal, "at the nozzle". This is significantly more than the depot-level purchase cost of $0.99/gal. The study concluded that the USAF's fuel pricing approach, "... prevents an end-to-end view of fuel utilization in decision making, does not reflect the DoD's true fuel costs, masks energy efficiency benefits, and distorts platform design choices." The fact that fuel costs have risen by 2-3 times since the DSB study does not significantly change these conclusions. Even at a price of $5 per gallon, the direct fuel costs would account for not more than 25% of the fully-loaded cost of the fuel.

To address the issue raised by the DSB, this study undertook a complete estimate of fuel costs "at the nozzle," including an estimate of the indirect costs associated with owning and operating the tanker fleet (Figure 12). The cost model for fuel included the following cost components: (1) direct (depot) cost of surface-delivered fuel, (2) the direct (depot) cost of fuel delivered via tanker to the receiving platforms, (3) the depot cost of fuel consumed by tankers during flight to and from the refueling point, and (4) the fully-loaded, non-fuel O&S costs for the tanker that are associated with flight to and from the refueling point[3]. The model did not include the basing costs, deployment costs, or other similar indirect costs for the tankers[4].

Fully-loaded (w/ tanker O&S costs) cost of fuel from a tanker grows exponentially with the refueling mission radius.

Tanker operating and support costs represent the the bulk of the effective fuel cost for refueling missions beyond a 500 mile radius.

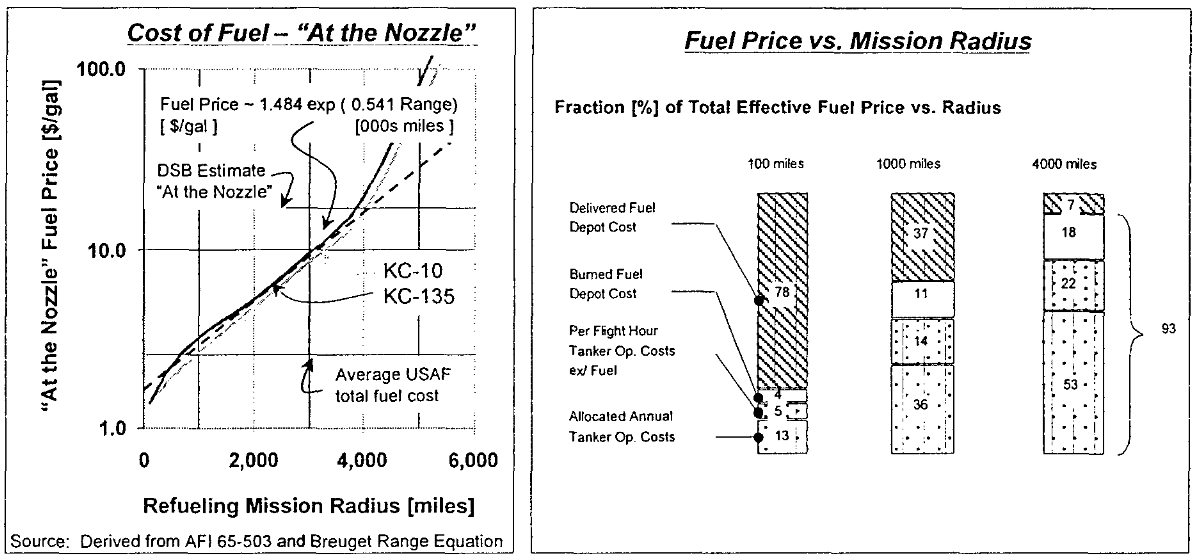


Fig. 12: Sources of refueling costs.

The depot cost of fuel delivered to platforms and tankers was calculated using the Air Force depot-level purchase cost of $0.99/gal. This estimate neglects surface-based distribution costs such as the cost of transporting fuel by ground, sea, or pipeline from the fuel depot to non-depot airbases.

The non-fuel O&S expenses for the tanker aircraft were modeled using the same approach described above for other platform types, and included crew costs, maintenance costs, depreciation and attrition costs, etc. In the case of the tankers, however, the payload was the delivered fuel. In addition, the model assumed that all tanker hours flown were mission hours[5]. This led to a unity utilization factor on non-fuel O&S costs.

[3] The model also accounted for the cost of fuel burned by the tanker during the transfer of fuel from the tanker to the receiving platforms. This cost is small in comparison to the other modeled fuel costs.

[4] This assumption yields a conservative estimate of tanker costs.

[5] This assumption is made to avoid double counting when, for example, a peacetime aerial refueling occurs in support of a training mission for a strike aircraft. While such a mission represents training for the strike aircraft, it represents an operational mission for the tanker. Because tankers do fly some training missions without delivering fuel, this assumption leads to a conservative, underestimated, "at the nozzle" fuel cost.

Basing and Deployment Costs

At the time the core analysis for this study was conducted, spring of 2003, there was very little publicly-available information on USAF basing costs. In particular, there was no equivalent to the AFI-65 503 database available for the modeling of base ownership and operations costs. In order to develop an estimate of basing costs, a simple top-down model was developed (Figure 13).

Deploying strike aircraft from their home bases to their forward bases during a campaign leads to substantial basing and deployment costs. These costs can represent a significant portion of total cost of a campaign.

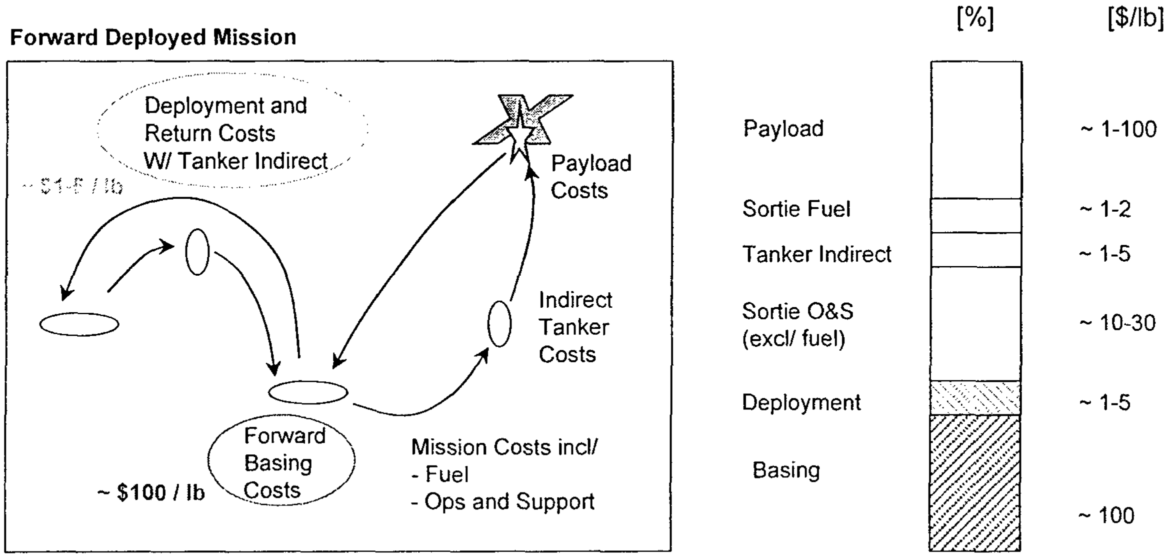


Fig. 13: The costs of forward deployment.

The simple basing cost model is shown in Figure 14. The result is an estimate for the average basing cost per ton delivered over some time interval. In order to perform this calculation, one needs an estimate for the average annual cost of operating from a typical overseas airbase. The basing cost estimate should only account for those costs paid by the US. This includes an amortized ownership cost if the base is US-owned or a leasing cost if the base is leased from a host nation. Complimentary or subsidized services provided by a host nation would not be considered a source of cost. An estimate of the number of overseas bases used in support of combat operations during the time interval, an estimate of the frequency with which combat operations occur during the time interval, and an estimate of the typical intensity of any single campaign or combat operation that occurred during the time interval are shown. The basing count should include all bases that played a role in support of a combat operation, to include those bases from which tankers, cargo aircraft, and ISR platforms operated in support of the strike mission.

Basing costs were modeled using the following simple cost model:

$$\underbrace{\frac{BASE\_COST}{PAYLOAD}}_{\sim \$100\ /\ \text{lb payload}} \approx \overbrace{\underbrace{\left[\frac{COST\ /\ YEAR}{BASE}\right]}_{\sim \$100\text{M}\ /\ \text{base}}}^{\text{Annual Base Operating Costs}} \cdot \overbrace{\underbrace{\left[BASES\right]}_{\sim 10\text{-}20\ \text{major bases}}}^{\text{Footprint}} \Big/ \overbrace{\underbrace{\left[\frac{PAYLOAD}{CAMPAIGN}\right]}_{\sim 20\ \text{M lbs / campaign}}}^{\text{Campaign Intensity}} \cdot \overbrace{\underbrace{\left[\frac{CAMPAIGN}{YEAR}\right]}_{\sim 1\ \text{campaign every 2 years}}}^{\text{Campaign Frequency}}$$

Fig. 14: Modeling overseas basing costs.

Because this study was conducted using only unclassified open-literature sources, it was not possible to develop an official, comprehensive and official list of US bases used in support of recent conflicts in Kosovo, Afghanistan, and Iraq. However, an Internet-based resource, GlobalSecurity.org, did provide reasonably extensive listings of US air bases used in support of these operations. Based on these listings, we estimated that the US used between 10 and 25 US-owned or US-leased overseas bases during each of the past three major air wars (Figure 15). Furthermore, this estimate is consistent with a Rand study which independently determined the overseas bases used for Operation Allied Force, Operation Enduring Freedom, and Operation Iraqi Freedom, respectively.

Kosovo

Tuzla	Bosnia
Istres	France
Ramstein AB	Germany
Ferihegy	Hungary
Taszar	Hungary
Aviano AB	Italy
Moron AB	Spain
Balikesir	Turkey
Bandirma	Turkey
Incirlik	Turkey
RAF Fairford	UK

... plus 11 other* bases in Italy, Germany and UK

Notes: * RAF Brize RAF Norton, RAF Lakenheath, RAF Mildenhall, RAF St. Morgan, Brindisi, Gioia Del Colle, Cervia-San Giorgio, NAS Sigonella, Geilenkirchen AB, Rhein Main AB, Spangdahlem AB

Source: Globalsecurity.org

Afghanistan

Diego Garcia	BIOT
Bourgas	Bulgaria
Souda Bay	Crete
Al Jaber AB	Kuwait
Ali Al Salem AB	Kuwait
Masirah AB	Oman
Seeb IAP	Oman
Thumrait AB	Oman
Al Udeid AB	Qatar
Constanta	Romania
Prince Sultan AB	Saudi Arabia
Incirlik AB	Turkey
Al Dhafra AB	UAE
RAF Fairford	UK

Source: Globalsecurity.org

Iraq

Bagram Airfield	Afghanistan
Muharraq Airfield	Bahrain
Diego Garcia	BIOT
Al Jaber AB	Kuwait
Ali Al Salem AB	Kuwait
Manas	Kyrgyzstan
Masirah AB	Oman
Seeb Int'l Airport	Oman
Thumrait AB	Oman
Jacobabad AB	Pakistan
Al Udeid AB	Qatar
Prince Sultan AB	Saudi Arabia
AL Dhafra AB	UAE

Source: Globalsecurity.org

Fig. 15: Estimate of overseas base footprint for 3 air wars.

The basing cost model in Figure 14 also requires an estimate of campaign intensity. These statistics are readily found in the open source literature, not only for recent air wars, but for every major air war in US history. As can bee seen in Figure 16, the US Air Force and, in some cases, other services and allies, delivered approximately 17 thousand, 10 thousand, and 6 thousand tons of ordnance by air during the recent air wars in Iraq, Afghanistan, and Kosovo, respectively. By contrast, approximately 61 thousand tons of ordnance were delivered by air during the 1991 Gulf War. Looking back even further, 6.2 million tons, 0.5 million tons, and 2.2 million tons of ordnance were delivered by air during the Vietnam Conflict, the Korean War, and World War II, respectively.

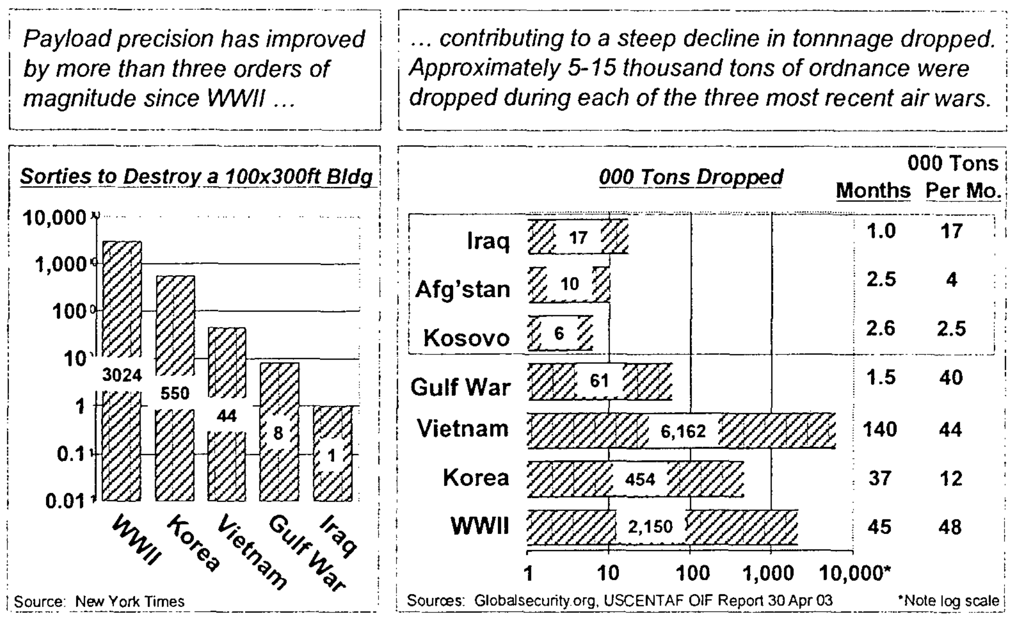


Fig. 16: Estimates of campaign intensity.

It is quite difficult to accurately identify all costs of operating a foreign air base from publicly-available data for a variety of reasons beyond the scope of this report. Therefore, we adopted a methodology based on data from the DoD base realignment and closure (BRAC) commission findings for domestic bases. A selection of domestic airbase closures is shown in Figure 17, together with the reported estimated annual savings associated with each closing. These estimates vary between \$61 million per year and \$174 million per year, in Fiscal Year 2003 dollars. We have chosen the simple, expedient approach of averaging the closures, which predicts a savings of about \$100M per year per base. We believe this to be a conservative (i.e. low) estimate. As a single point of comparison, a 2003 New York Times editorial claimed that US expenditures on USAF and US Army bases in Germany totaled \$8 billion per year, with Ramstein alone costing \$1000M per year. Ramstein is a very large base and so is not representative of the typical US overseas base, making \$1000M per year an upper estimate on annual base costs. Averaging the remaining costs across the 25 other bases that existed in Germany at that time yields an average cost of \$240M, which is consistent with the BRAC-inspired estimate of \$100M per base. More recently (NY Times, July 13, 2006), it was reported that the closings of the US airbase in Reykjavik, Iceland is expected to save \$250M per year. This is consistent with the BRAC-based estimate.

Available data places annual base operating costs at between $50M and $1B per year.
This study assumed a basing cost of $100 million per overseas air base per year.

	Base	Location	[$M / year]
Overseas Bases	Ramstein	Germany	1000
	Other*	Germany	240
Domestic BRAC Closures**	Kelly	TX	174
	McClellan	CA	158
	Pease	NH	148
	Norton	CA	123
	Sawyer	MI	105
	Mather	CA	103
	Loring	ME	100
	Chanute	IL	98
	Castle	CA	88
	Eaker	AR	88
	George	CA	83
	England	LA	80
	Grissom	IN	80
	Carswell	TX	75
	Griffiss	NY	69
	Plattsburgh	NY	67
	Homestead	FL	61

Notes: * Average cost of 25 USAF and US Army bases in Germany.
** Reported numbers are final year cost savings for BRAC bases inflated to FY03 dollars

Sources: USAF BRAC; New York Times

Fig. 17: Overseas basing costs were extrapolated from domestic BRAC estimates.

Each of the three most recent air wars used between 10 and 25 overseas bases. The basing cost model presented here is a general basing model, and makes conservative cost assumptions. As a result, the basing model may underestimate the actual, total, fully-loaded, annual basing costs for the USAF. Substantially improved cost estimates could be developed using a detailed cost model derived from an accounting database that includes the detailed costs of all current US overseas bases. Future studies should make use of such a database.

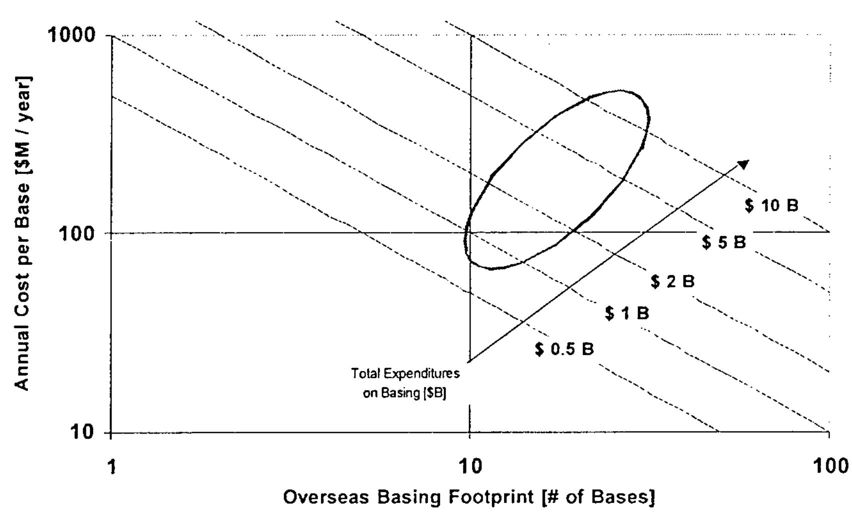


Fig 18: The overseas-basing funding stream is large.

Another approach is to treat the base cost as a parameter. Figure 18 shows an estimate of the savings which can be realized from closing overseas bases as a function of the cost of each base and the number of bases. Depending on estimates of footprint and base operating cost, the estimated total expenditure on overseas basing is quite large, in the range of $1B to $10B.

TECHNICAL APPROACHES TO INCREASING AIRCRAFT RANGE

The cost study discussed above found that increasing aircraft range to reduce basing requirements may have significant economic benefit. How much range is necessary? The data in Figure 19 shows the distances needed to reach various locations around the world from the continental U.S. (CONUS), the U.S. (including Hawaii and Alaska), the US plus possessions (Guam), the US territories plus Diego Garcia. With the exception of Cape Town, most places are less than 6500 statute miles from CONUS, and 4500 mi when the territories and Diego Garcia are included. Of course, this radial distance must be doubled to determine round trip range and reserves must be added for diversion and other contingencies. Overall, however, about 13,000 mi range is required to visit any place on earth starting from the United states or its possessions. This can serve as a working definition of the range requirement for a global range aircraft. Should regional bases be available in the UK and Diego Garcia, this requirement can be reduced by about a factor of two.

Location	Position		Distance from US Bases			
	Lat	Long	CONUS	w/ HI, AK	w/ Territories	w/ Diego Garcia
Belgrade	45.0	21.0	4581	4581	4581	4581
Kabul, Afghanistan	34.5	69.2	6680	5142	4888	2899
Baghdad, Iraq	33.3	44.4	6048	5563	5563	3359
Mosul, Iraq	36.3	43.2	5848	5370	5370	3564
Beijing, China	39.8	116.5	5417	3678	2501	2501
Shanghai, China	32.1	118.8	5769	4070	2088	2088
Taipei, Taiwan	25.1	121.5	6053	4414	1716	1716
Pyongyang, N. Korea	39.0	125.7	5152	3459	2114	2114
Monrovia, Liberia	6.3	(10.8)	4561	4561	3750	3750
Dili, East Timor	(8.6)	125.6	7679	5150	2027	2027
Ulaanbaatar, Mongolia	47.9	106.8	5226	3468	3221	3221
Cape Town, S. Africa	(34.0)	18.6	7791	7791	6582	3881
Tierra del Fuego, Chile	(54.8)	(70.2)	5734	4916	4916	4916

Fig 19: The range need to reach selected places from the US and territories.

There are many technical solutions to achieving global range. These range from the multiple refueling of existing short-range aircraft to the design of new long-range aircraft, with many solutions between these limits. The B-2 bomber reportedly has a range of about 7000 mi

while the longest range commercial transport aircraft, the Boeing 777-200, has a range of greater than 10,000 mi. One solution to achieving global range without requiring new technology is simply to build larger versions of current aircraft types, trading payload fraction and aircraft cost for longer range. However, there are several promising technical approaches to increasing aircraft range without large sacrifices in payload capability and cost. These combine innovative configurations with improvements in aerodynamics, propulsion, and structures which bring disproportionate benefit to long-range aircraft.

One particularly attractive, innovative concept suggested by Dr. Mark Drela is the oblique supersonic flying wing illustrated in Figure 20. The advantage of an oblique flying wing is that it has essentially optimum aerodynamics for both subsonic and supersonic flight conditions and so does not suffer from the poor subsonic performance characteristics of most long-range supersonic aircraft configurations. This makes it ideal as a multi-mission military aircraft which may need high speed for fast response or survivability on some occasions and long endurance loiter capability for others. The principal design constraint is that the supersonic cruise Mach number must be limited to the 1.6-1.8 range for this to be an attractive concept. It can be considered an aerodynamically morphing aircraft.

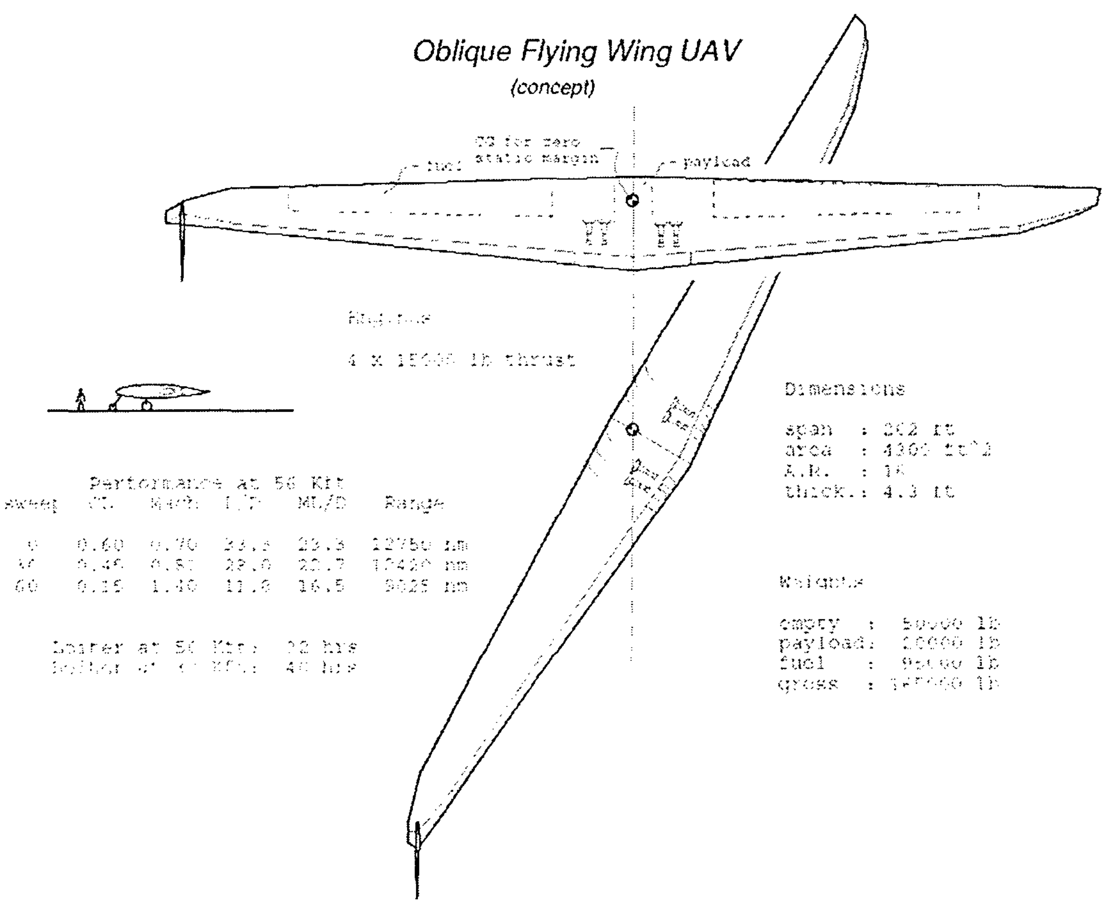


Fig 20: An oblique supersonic flying wing, very long range strike aircraft concept.

The pioneering work of NASA in the 1970s and 1980s on oblique wings elucidated its value but also encountered the problem of aircraft scale. The requirements for headroom and volume for passengers forced the aircraft to grow to 600 ft span, more than twice that of current

large aircraft. Given the high density of munitions and avionics, this constraint disappears for many military applications. The aircraft concept in Figure 20 is sized to carry a standard 20,000 lb bomb bay. It is the size of a commercial transport wing and weighs about 165,000 lb. This is only one advanced concept, although particularly attractive when unrefueled global range is needed. Many others are feasible as well.

DISCUSSION

There are several implications of realization that foreign bases can be the dominant element in the cost of fighting an air war. One is that the funding stream which supports foreign bases is significant (Figure 18) and these funds could conceptually be redirected toward the purchase of long-range aircraft (with Congressional approval, of course). Thus it may be possible to partially fund the procurement of new long-range aircraft from these savings.

Another way of viewing this is that transforming to global range aircraft transfers funds from the base maintainers to the platform manufacturers and maintainers, helping to support the aerospace industrial base without changing the Air Force top line (Figure 21).

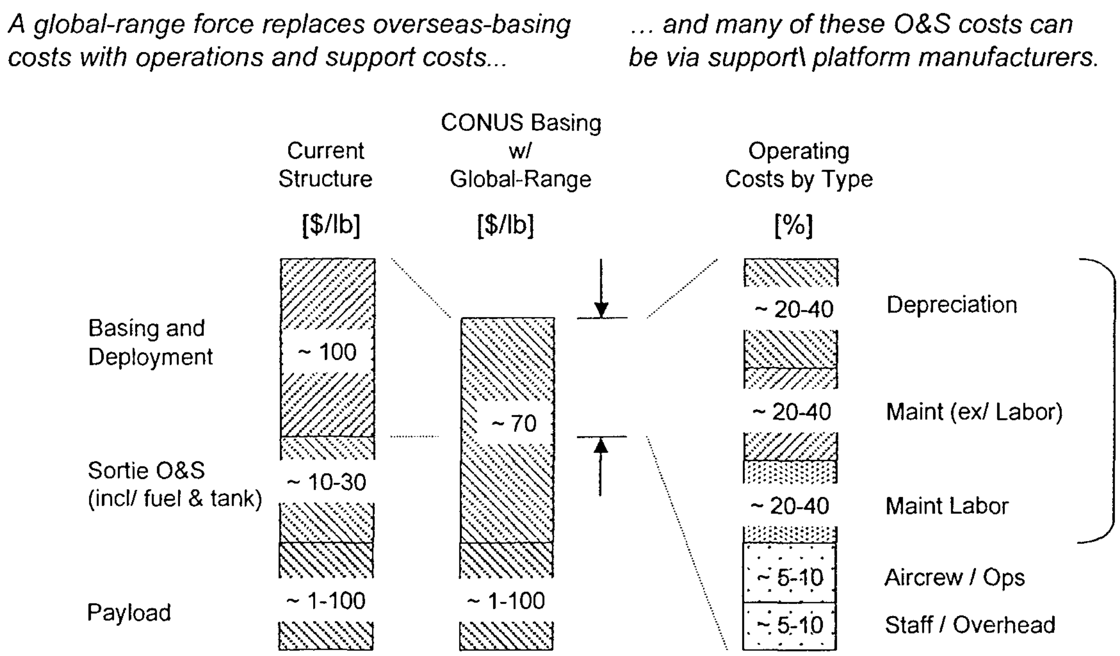


Fig 21: A global-range force transfers a funding stream to platform suppliers and maintainers.

A second implication of the dominance of base costs is that moving from piloted to uninhabited combat vehicles (UCAV) will not accrue significant savings if the UCAVs are designed to operate from the same base structure as do current aircraft (Figure 22). Also, very long ranges, and therefore very long flight times, are a strain for humans. So, unpiloted vehicles may be increasingly attractive as mission lengths increase.

With overseas basing, the O&S cost savings from UCAV operations lead to only a small overall cost savings because basing costs dominate...

... while CONUS basing makes O&S the dominate cost, amplifying UCAV savings.

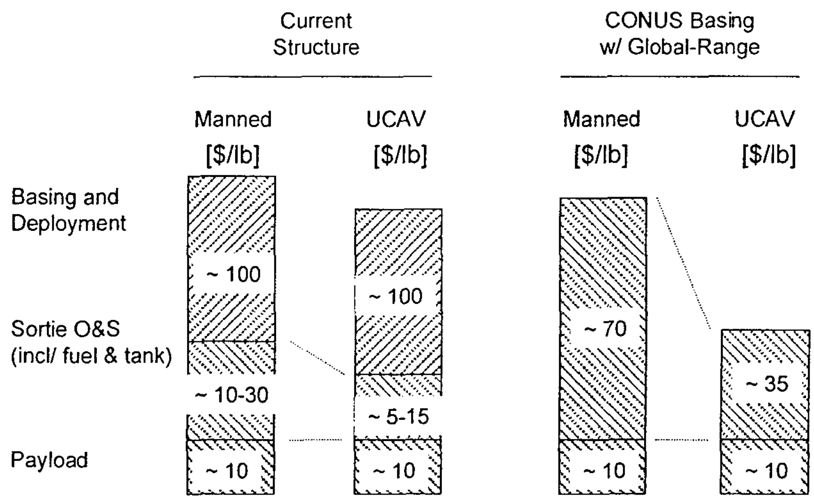


Fig 22: Global-range capability enhances UCAV cost savings.

CONCLUSIONS

This study has found that in the new world of precision munitions, the cost of maintaining foreign bases needed to support air operation of the current, relatively short-range USAF is the dominant cost element, consuming up to 50-60% of the total funds. This is a very significant change from earlier wars, such as Vietnam, where aircraft operations and support costs dominated. Base costs were not a major element. This stems from spreading a decreased number of operations (due to precision) over a relatively fixed number of foreign base structures. Since base costs are not called out explicitly in DoD budgets (indeed are difficult to deduce), the magnitude of this change has been previously unrecognized.

This gives new impetus to the concept of global range aircraft. In addition to providing flexibility and a reduction on foreign base dependence, such an aircraft could also significantly reduce the cost of fighting a modern air war. There are many technical solutions for realizing such aircraft. One particularly attractive approach is the oblique supersonic flying wing aircraft. The cost savings from relinquishing many of the foreign bases may provide several billion dollars per year in savings, suggesting that a cash stream to partially pay for such vehicles may be available.

The recognition of the true costs of the current approach of a combination of foreign bases and air-refueling suggests that the DoD would be well-served to examine other aeronautical systems and approaches.